Reduction of Accessory Overdrive and Parasitic Loading on a Parallel Electric Hybrid City Bus

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Acknowledgements

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  - University of Minnesota Center for Transportation Studies

Energy Audit for Hybrid Buses

- In current buses, both conventional and hybrid, a significant amount of power is used to provide the “hotel load”
  - Hotel load consist of power for air conditioning, steering, doors, cooling pumps, etc.
  - This power is currently generated very inefficiently, especially when the buses is stationary or moving slowly
  - It is unclear how much and when this power is actually needed
- This project involved instrumenting a current technology parallel hybrid bus and auditing its energy use

Electrification Studies

- Army [1]
  - “Silent Watch”: 600% improvement
  - Overall: 20% improvement
- EMP [2]
  - 5-10% improvement (CATA, TriMet)

Why so uncommon?

[1] Filipi, Z., Louca, L., Stefanopoulou, A, et al. “Fuel Cell APU for Silent Watch and Mild Electrification of a Medium Tactical Truck,” SAE paper 2004-01-147

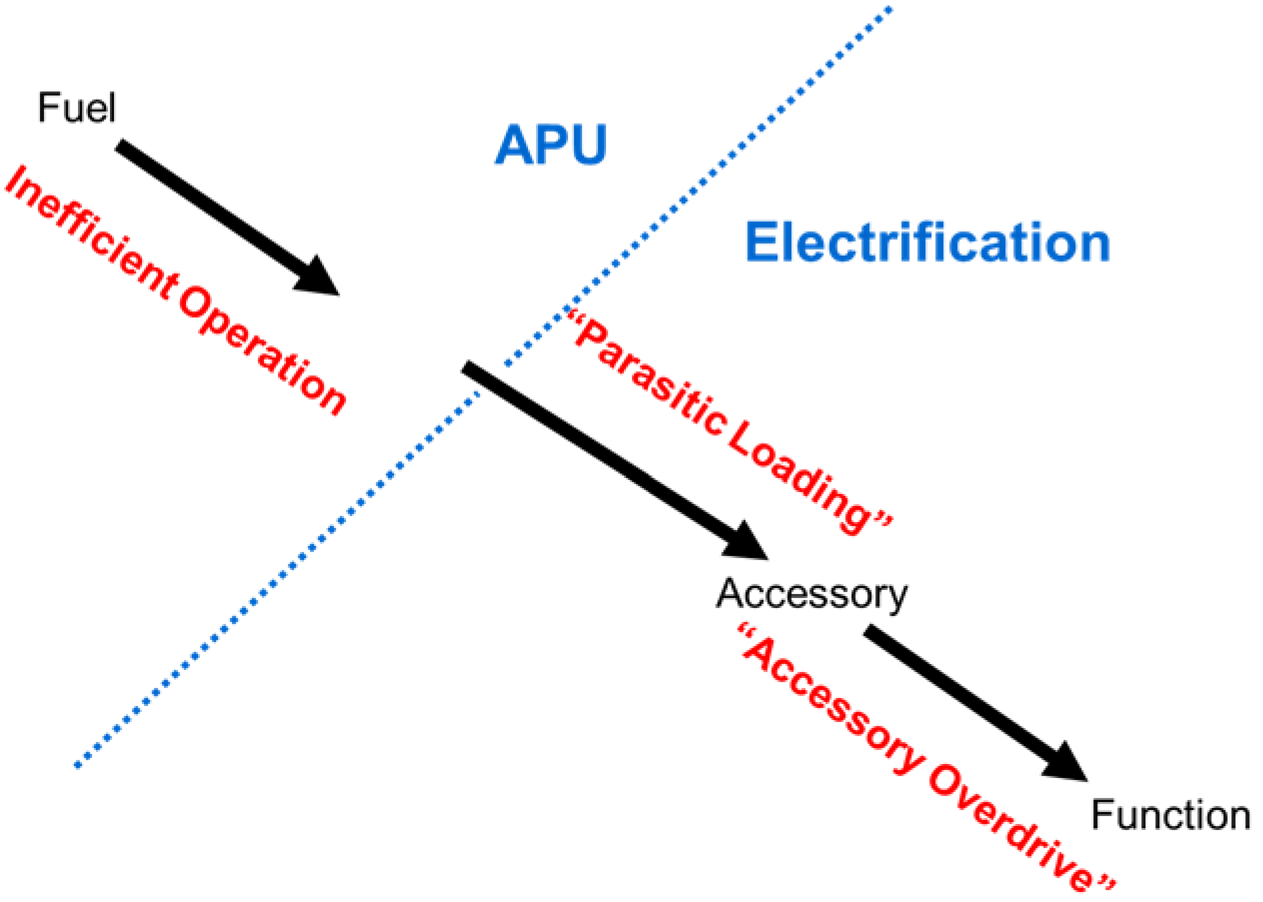
[2] Page, R., Bedogne, R., Steinmetz, T., “A “Mini-Hybrid” Transit Bus with Electrified Cooling System.” SAE Paper 2006-01-3475, 2006

The Bus

- 40’ Gillig Low-Floor Bus
  - Parallel Hybrid Meeting 2007 emission standards
  - Purchased by Metro Transit: March 2008

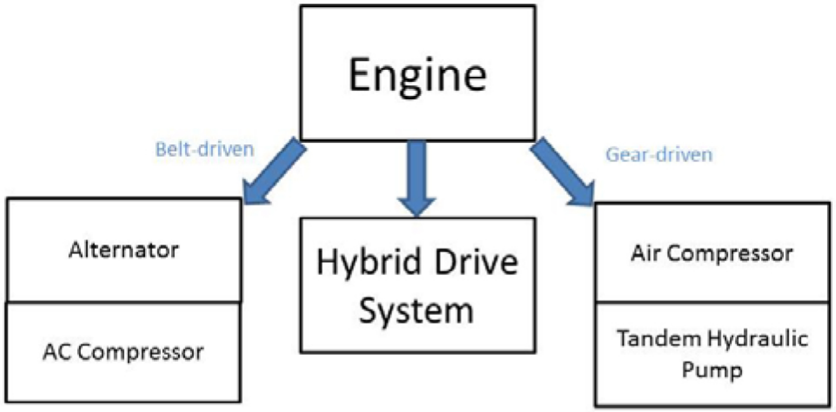
Curb Weight:	29,550 lbs (13,400 kg)
Length	41.5 ft (12.6 m)
Width	8.3 ft (2.5 m)
Height/Height with Battery	9.0 ft/10.5 ft (2.7 m/3.0 m)
Wheelbase	23.3 ft (7.1 m)
Engine Type	2007 Cummins ISB
Rated Torque	620 lbf-ft (841 Nm) @ 1600 RPM
Rated Power	260 HP (194 kW)
Hybrid Drive System	Allison EP40
Passenger Capacity	38 seated, 28 standing

Accessory Efficiency Breakdown

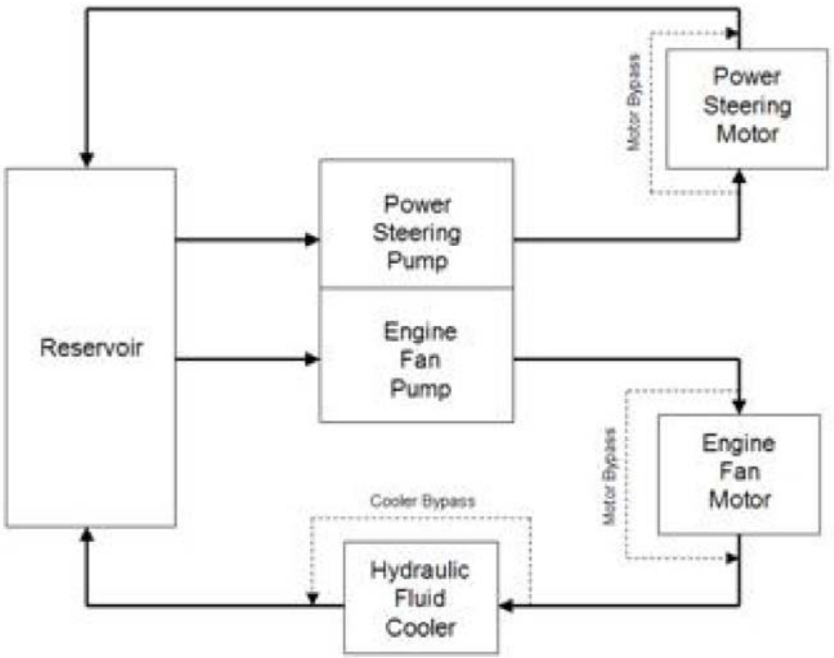


Accessory drive systems

Directly driven systems



Systems powered by hydraulic drive



Experimental Setup

The Four Major Accessories Analyzed

- Tandem Hydraulic Pump (Engine Fan and Power Steering)
- Air Conditioning System (Compressor and Fans)
- Air Compressor
- Alternator

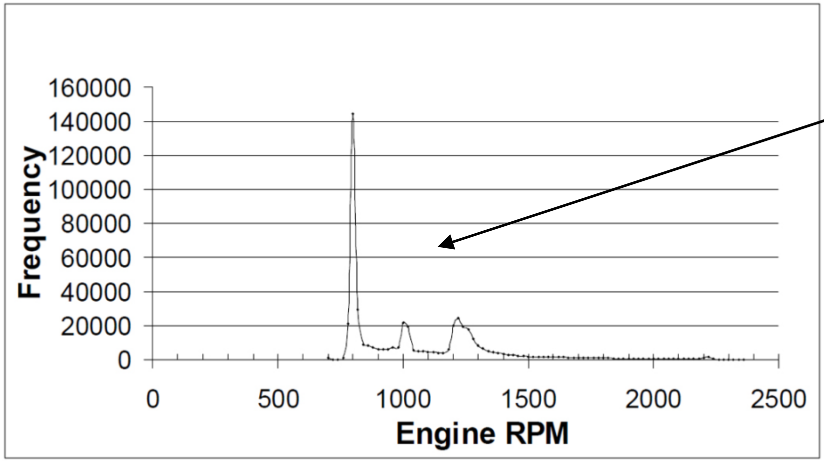
Data Aquisiton System

- NI Compact FieldPoint

Collection Details

- 10 day period
  - 145.6 hours of run time
  - Half a million timestamps
    - 39% AC on
    - 61% AC off

Test schedule and vehicle and engine speed histograms



Three principal engine speed modes – low and high idle and main hybrid propulsion drive speed

Date	Start - stop times	Collection duration (hrs)
Aug 27th	04:32 - 24:08	16.5
Aug 28th	05:50 - 25:55	18.2
Aug 29th	12:25 - 23:11	9.9
Aug 30th	17:24 - 26:15	7
Aug 31st	07:27 - 23:17	15.5
Sept 1st	05:40 - 25:12	18.2
Sept 2nd	07:30 - 19:19	6.2
Sept 3rd	05:50 - 19:19	12.6
Sept 4th	05:31 - 25:29	17.9
Sept 5th	14:13 - 19:26	13.3
Sept 8th	06:23 - 19:22	10.3
Total	NA	145.6

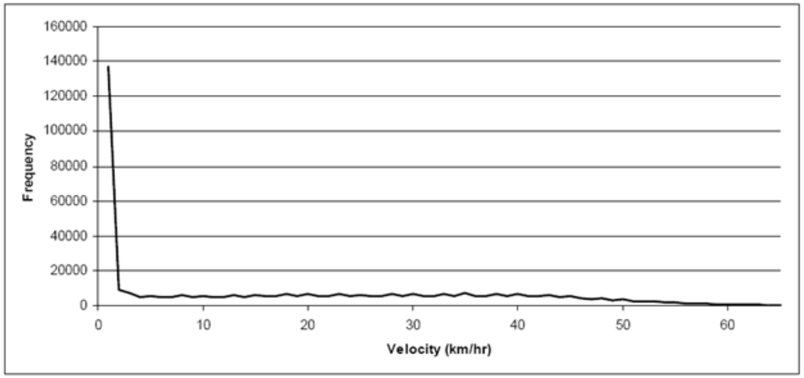


Figure 8: Bus Velocity Histogram

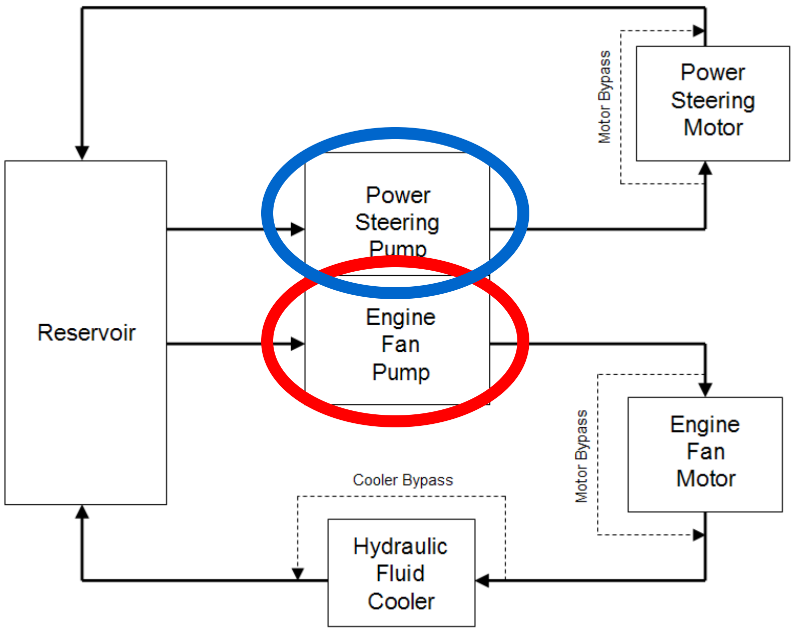
Median speed 8 km/hr; mean speed 16 km/hr

Instrumentation Example: Hydraulic Loads

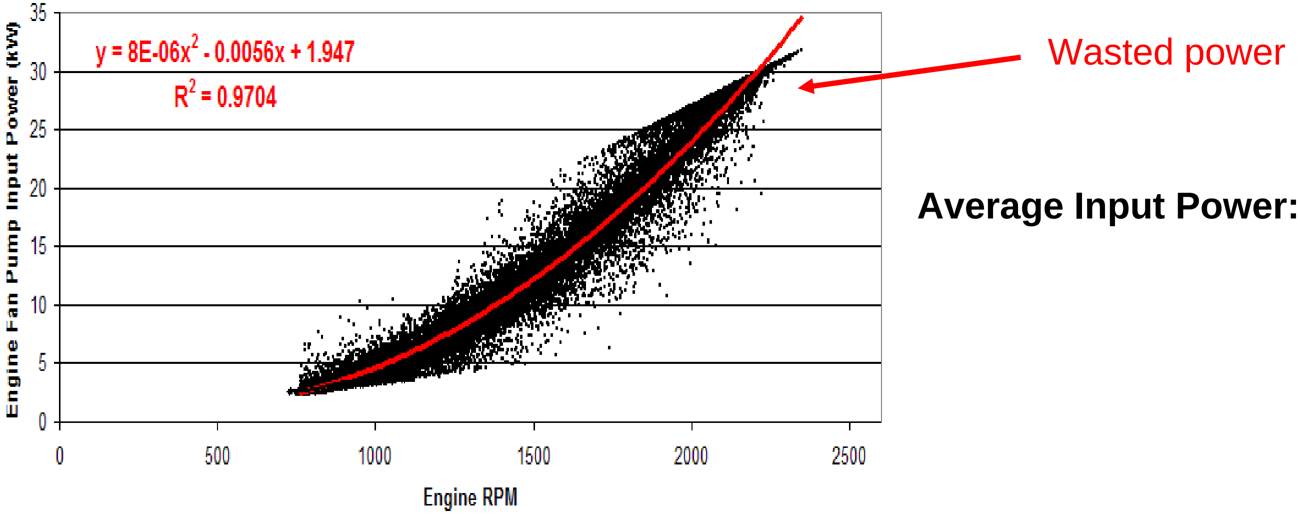
- **Goal**
  - Calculate Input Power once per second for each circuit

$$P_{in} = \frac{\omega * Vol * \Delta P}{\eta_{mechanical}}$$

- **Knowns**
  - Engine Speed
  - Pump Displacement
- **Unknowns**
  - Pressure Differential
    - Transducers
  - Mechanical Efficiency
    - Manufacturer Performance Data

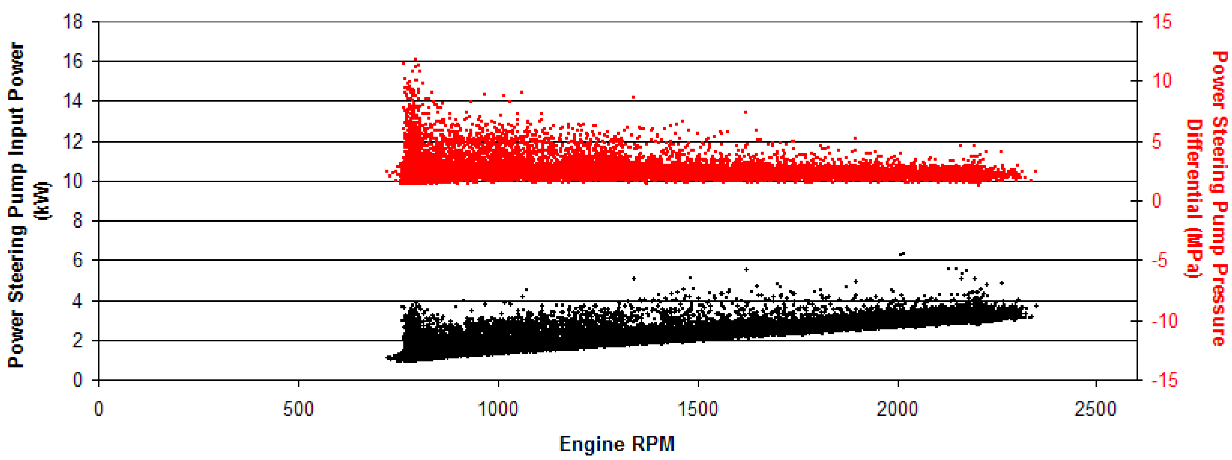


Hydraulic Loads



Average Input Power: 6.2 kW (engine fan)

1.8 kW (power steering)



Power use histograms for components driven hydraulic pump

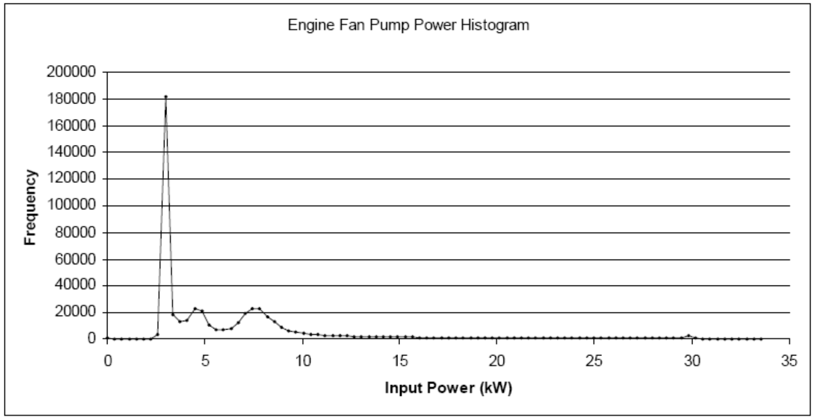


Figure 15: Engine Fan Input Power Histogram

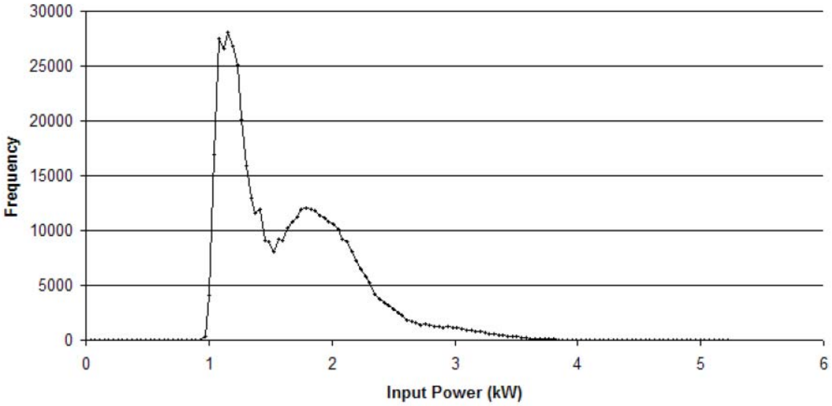


Figure 17: Power Steering Pump Input Power Histogram

Considerable air compressor power consumption in unloaded state

Air compressor power inputs

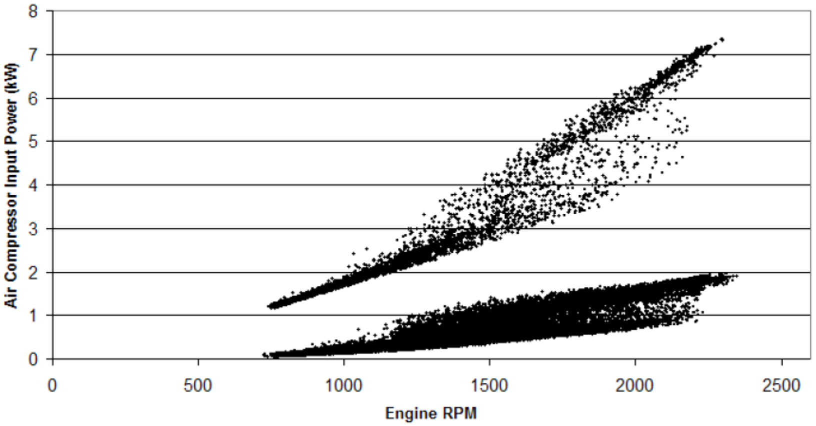


Figure 20: Air Compressor Input Power vs. Engine RPM

Air compressor power use histograms

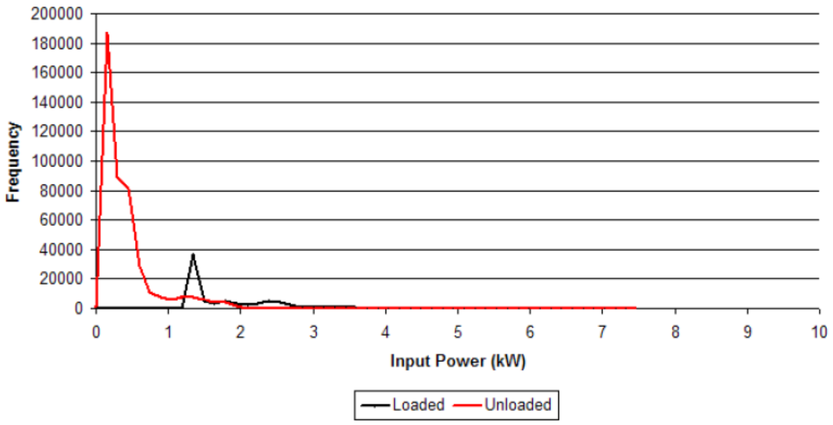


Figure 21: Air Compressor Input Power Histogram

The air conditioning system was a major power consumer both for compressor and electric fan drive

Table 5: Daily Air Conditioning Performance

Date	Hours of Data Collection	Time at No Load	Time at 1/3 Load	Time at 2/3 Load	Time at Full Load	Peak Temp (°C)	Average Temp (°C)
Aug 27th	16.5	100%	0%	0%	0%	29	22
Aug 28th	18.2	57%	<1%	5%	38%	32	22
Aug 29th	9.9	20%	<1%	2%	78%	36	28
Aug 30th	7.0	52%	<1%	<1%	48%	38	26
Aug 31st	15.5	25%	<1%	<1%	75%	37	28
Sept 1st	18.2	23%	<1%	3%	74%	39	29
Sept 2nd	6.2	95%	<1%	<1%	5%	29	21
Sept 3rd	12.6	50%	<1%	49%	1%	29	27
Sept 4th	17.9	91%	<1%	6%	2%	23	17
Sept 5th	13.3	76%	<1%	2%	22%	29	19
Sept 8th	10.3	100%	0%	0%	0%	28	18
Total	**145.6**	**61%**	**<1%**	**6%**	**32%**	**39**	**23**

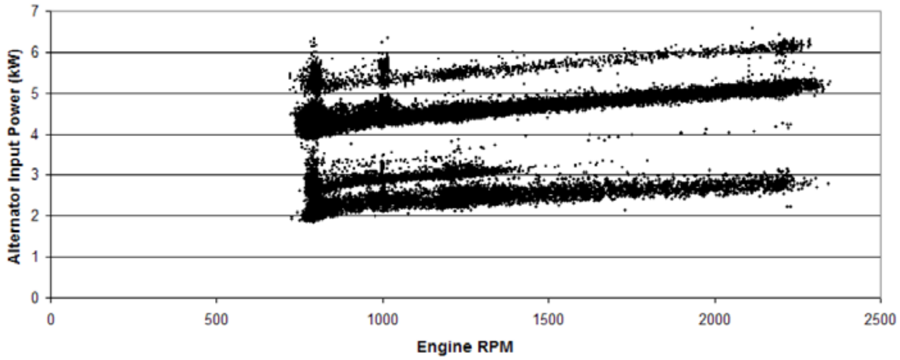


Figure 22: Alternator Input Power vs. Engine RPM

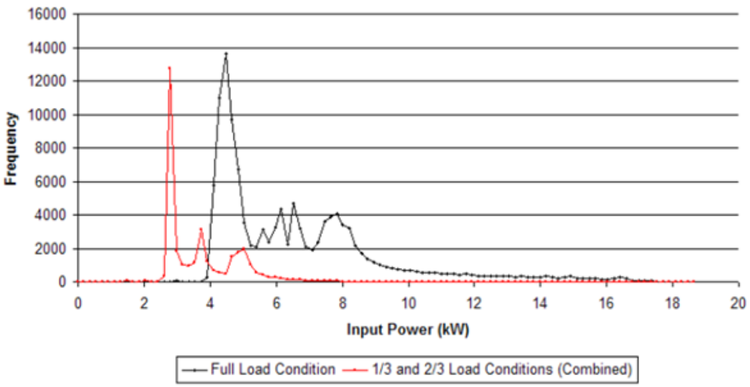


Figure 19: AC Compressor Input Power Histogram

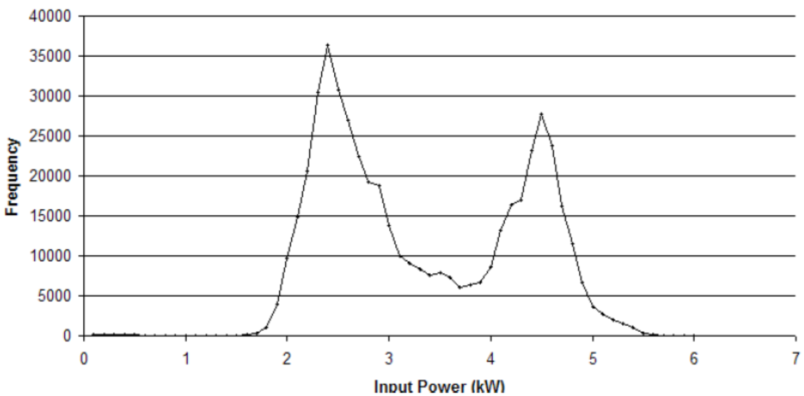
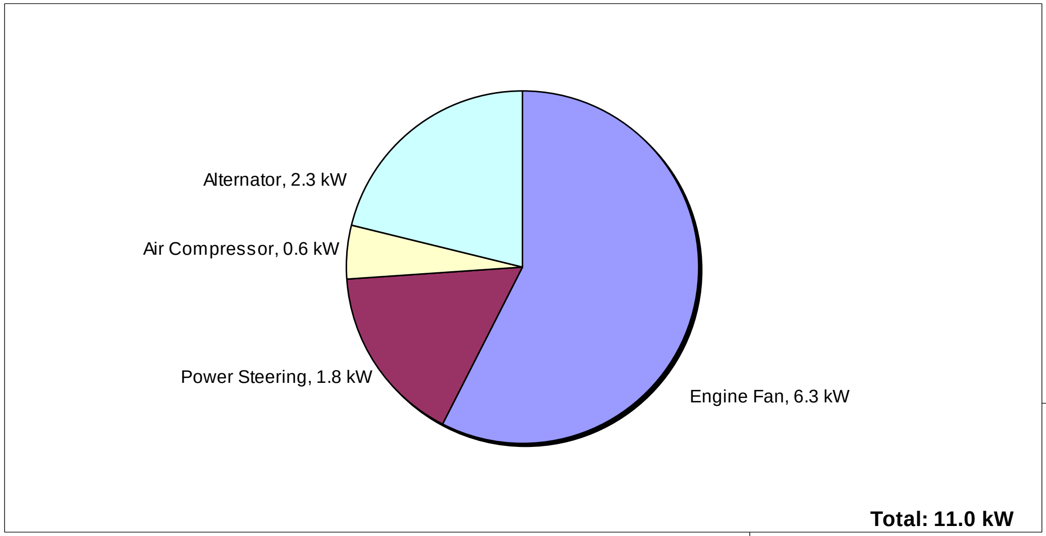
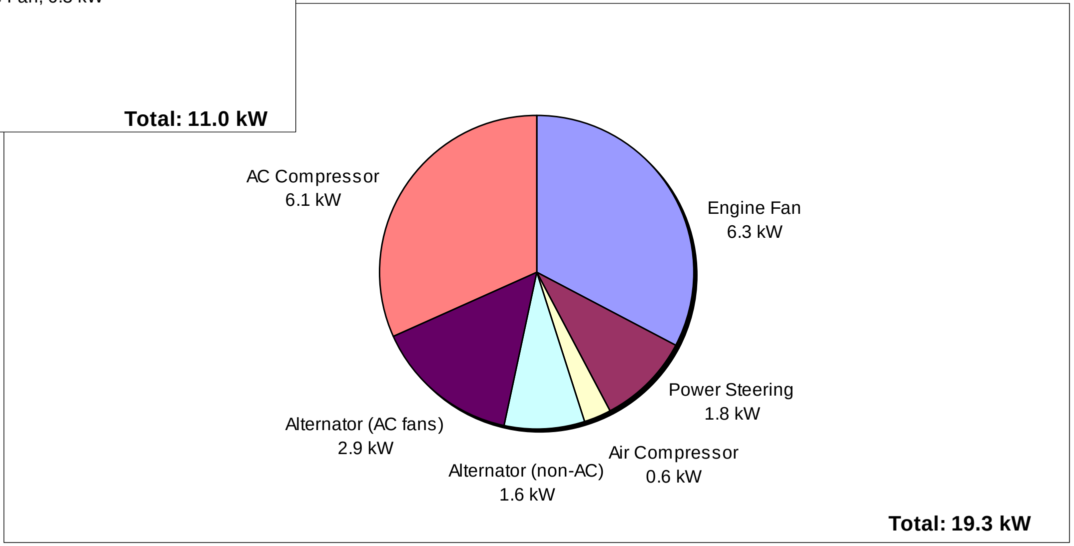


Figure 27: Alternator Input Power Histogram

Overall Results – average accessory loads



AC Off



AC On

How much could we gain through electrification of accessories?

Estimating potential savings

- Assume:
  - All electrically-driven accessories operate only at the idling power input of their mechanically-driven counterparts.
  - This “idle” condition provides enough power to perform the accessory’s function at all times, and
  - Each accessory is given a means to decouple itself from the engine’s rotational speed when its function is not needed

	Original Average Input Power (kW)	Theoretical Average Input Power (kW)	Average Load Reduction (kW)	Average Load Reduction (%)
Engine Fan Pump	6.3	3.2	3.1	49%
Power Steering Pump	1.8	1.2	0.6	34%
AC Compressor	0 / 6.1	0 / 4.1	0 / 2.0	33%
Air Compressor	0.58	0.29	0.29	50%
Alternator	2.3 / 4.5	2.3 / 4.5	0	0%
Total	**11.0 / 19.3**	**7.0 / 13.3**	**4.0 / 6.3**	**36% / 31%**

Note: The pairs of values in the “AC Compressor”, “Alternator” and “Total” rows represent values for when the AC system is off and when it is on.

Engine fan and AC drive account for about 80% of potential savings!

Potential savings through accessory electrification

- 40’ Gillig Low-Floor Hybrid
- Base fuel economy ~ 25 % better than non-hybrid
- For the test conditions of this study complete electrification of accessories could lead to an additional 13-15% fuel savings

Next steps

- Potential 13 - 15% increase in fuel economy for complete electrification.
- Even the relatively simple change to engine fan electrification should lead to a 5-10% improvement.
- Reductions in CO_2 emissions equal fuel savings assuming no fuel change

- Planned follow on work includes
  - Extend audit to three types of buses in the Metro Transit bus fleet
    - Standard diesel bus
    - Parallel hybrid bus
    - Fully electrified series hybrid bus – two have been recently purchased by MTC through FTA Tigger II grant.
  - Develop methods to analyze the collected data and methods to link it to data collected by Metro Transit.
  - Use analyzed data to improve and calibrate models of bus performance and emissions.
  - Examining the utility of using auxiliary power units (APUs) to generate this energy
  - Installing and testing a high efficiency Diesel APU and eventually a solid oxide fuel cell APU

Thank you, questions?